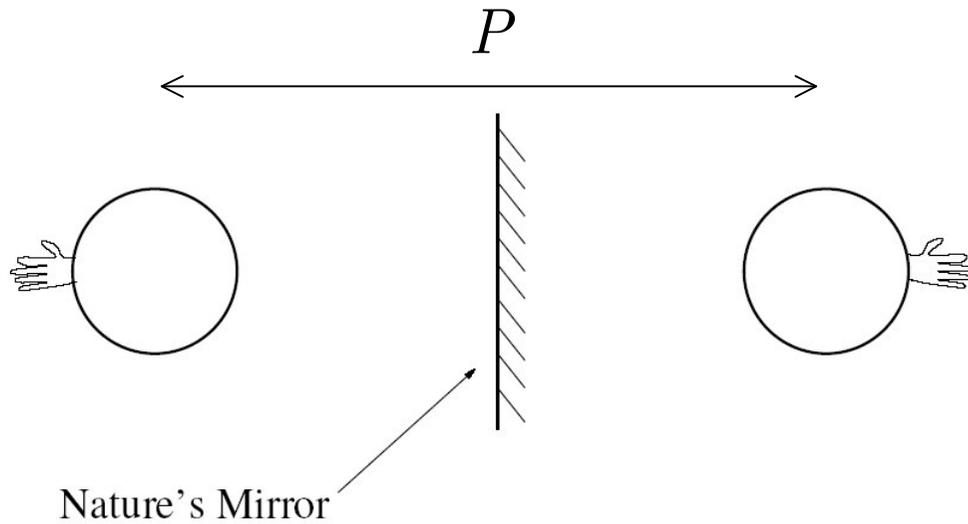


An experimental limit on neutron mirror-neutron oscillation

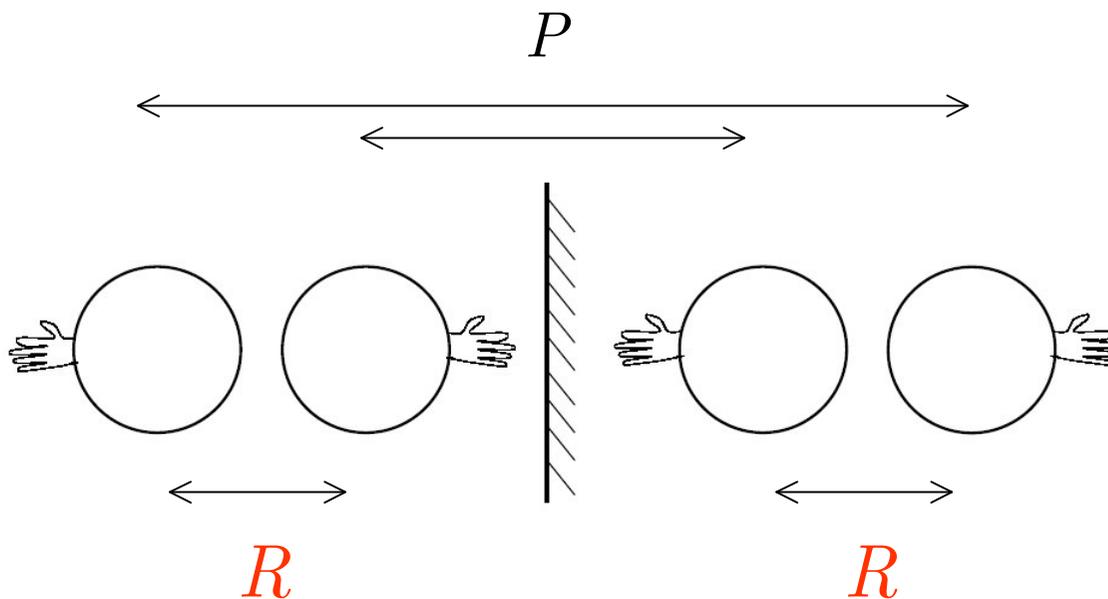
Ulrich Schmidt

Physikalisches Institut, Universität Heidelberg, Germany

What are mirror particles ???



World is not
 P symmetric



World is PR
symmetric

Properties of mirror particles

e		e'
ν		ν'
p		p'
n		n'
\bar{e}		\bar{e}'
$\bar{\nu}$		$\bar{\nu}'$
\bar{p}		\bar{p}'
\bar{n}		\bar{n}'
γ		γ'
W, Z		W', Z'
G		G'

For each particle exists a mirror particle which has exactly the same properties in the mirror world, as the particle in the world beside handedness.

Interaction between particles and mirror particles: gravity

Possible interaction between particles and mirror particles:

Oscillations/mixing between neutral particles and mirror particles

$$\gamma \leftrightarrow \gamma'$$

$$\nu \leftrightarrow \nu'$$

$$n \leftrightarrow n'$$

phenomenology of $n \leftrightarrow n'$ oscillation

$$L = \bar{\Psi} M \Psi, \quad \Psi = \begin{pmatrix} n \\ n' \end{pmatrix}, \quad M = \begin{pmatrix} m+V & \delta m \\ \delta m & m+V' \end{pmatrix}$$

$$n'(t) = n(0) \frac{\delta m^2}{\delta m^2 + \Delta E^2} \sin^2(\sqrt{\delta m^2 + \Delta E^2} \cdot t / \hbar) \quad \text{with} \quad \Delta E = V - V'$$

free flying neutron: only magnetic field counts for ΔE

$$\omega_L = \frac{\Delta E}{\hbar} = \frac{\mu B}{2\hbar} \quad \tau_{osc} = \frac{\hbar}{\delta m}$$

$$n'(t) = n(0) \frac{1}{1 + (\omega_L \tau_{osc})^2} \sin^2\left(\sqrt{1 + (\omega_L \tau_{osc})^2} \cdot \frac{t}{\tau_{osc}}\right)$$

$$n'(t) = n(0) \frac{1}{1 + (\omega_L \tau_{osc})^2} \sin^2 \left(\sqrt{1 + (\omega_L \tau_{osc})^2} \cdot \frac{t}{\tau_{osc}} \right)$$

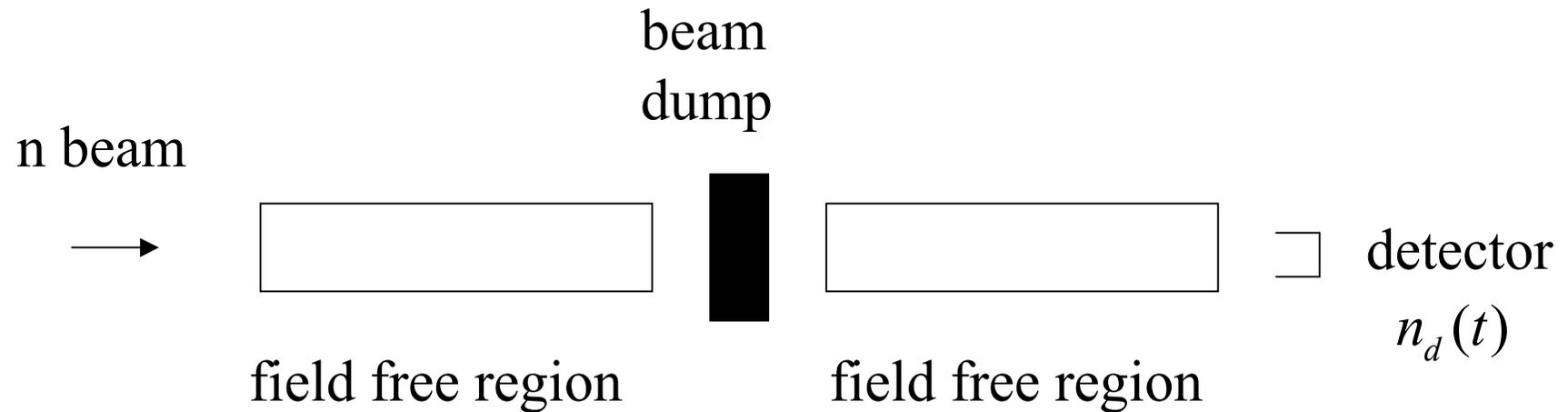
“field free” region

$$n'(t) = n(0) \left(\frac{t}{\tau_{osc}} \right)^2, \quad \omega_L t \ll 1, t < \tau_{osc}$$

magnetic field strongly suppress $n \leftrightarrow n'$ oscillation

$$n'(t) < n(0) \frac{1}{(\omega_L \tau_{osc})^2}, \quad \omega_L t \gg 1$$

Reappearance experiment



$$n'(t) = n(0) \left(\frac{t}{\tau_{osc}} \right)^2$$

$$n_d(t) = n'(0) \left(\frac{t}{\tau_{osc}} \right)^2$$

$$n_d(t) = n(0) \left(\frac{t}{\tau_{osc}} \right)^4$$

Disappearance experiment

n beam



field free region

$$n'(t) = n(0) \left(\frac{t}{\tau_{osc}} \right)^2$$

principle of our measurement:
measuring loss of neutrons
due to $n \leftrightarrow n'$

Problem: loss of neutrons due
to β -decay, scattering ...

But !!

Only $n \leftrightarrow n'$ is suppressed by a moderate magnetic field (0.1 mT)

$$R = \frac{\text{count rate without magnetic field}}{\text{count rate with magnetic field}} = 1 - \left(\frac{t}{\tau_{osc}} \right)^2$$

$$R \pm \Delta R \text{ is compatible with } 1 \Rightarrow \tau_{osc} \geq \frac{t}{\sqrt{\Delta R}}$$

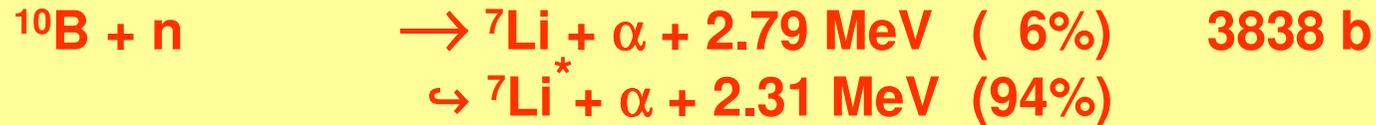
RESEDA am FRM II



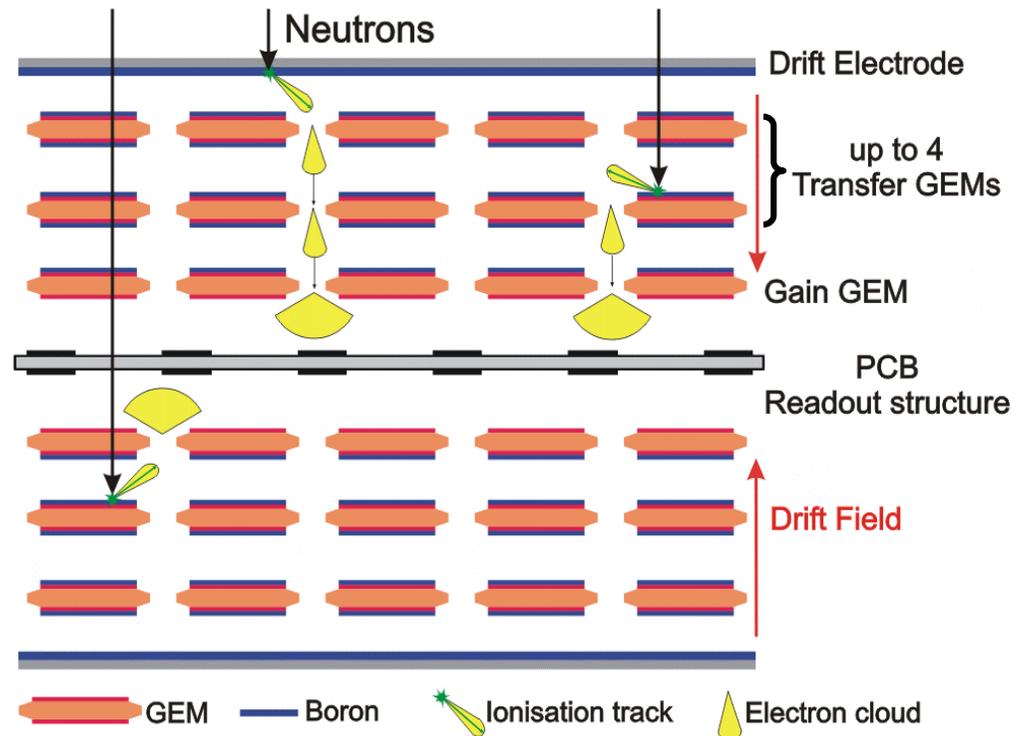
CASCADE: Multiple Boron Layers on GEMs

Problem:
n-counting at very high rates

Conventional (^3He -counters): $< 10\text{kHz}/\text{cm}^2$
 CASCADE: up to $10\text{ MHz}/\text{cm}^2$



- GEMs can be operated to be transparent for charges!
 → they can be cascaded!
- Each one can carry two Boron layers.
- Last one operated as amplifier.

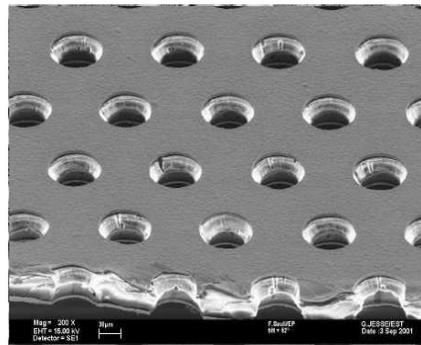


Accumulate single layer detection efficiency up to 50% for thermal neutrons (1.8\AA) and up to 75% for cold neutrons (5\AA).

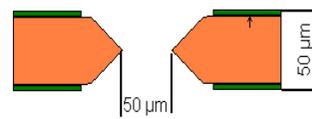
The Gas Electron Multiplier (GEM)

Amplifier Mode

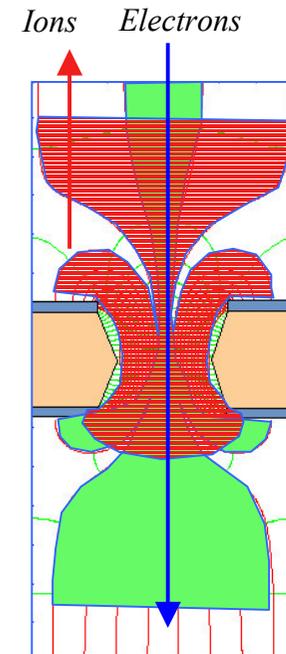
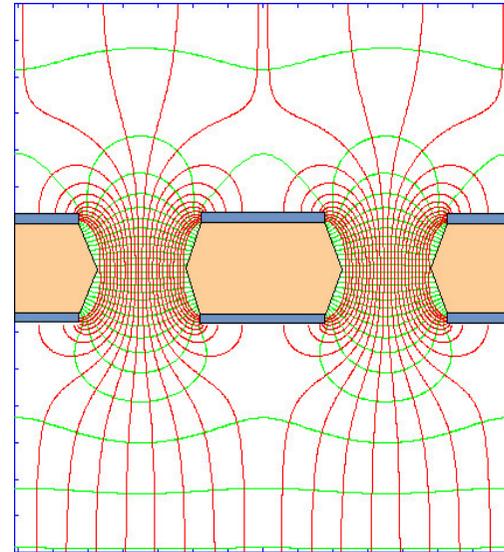
- In hole high fields allow Gas amplification 1 - 400



GEM-hole



Orange Kapton
Green Copper

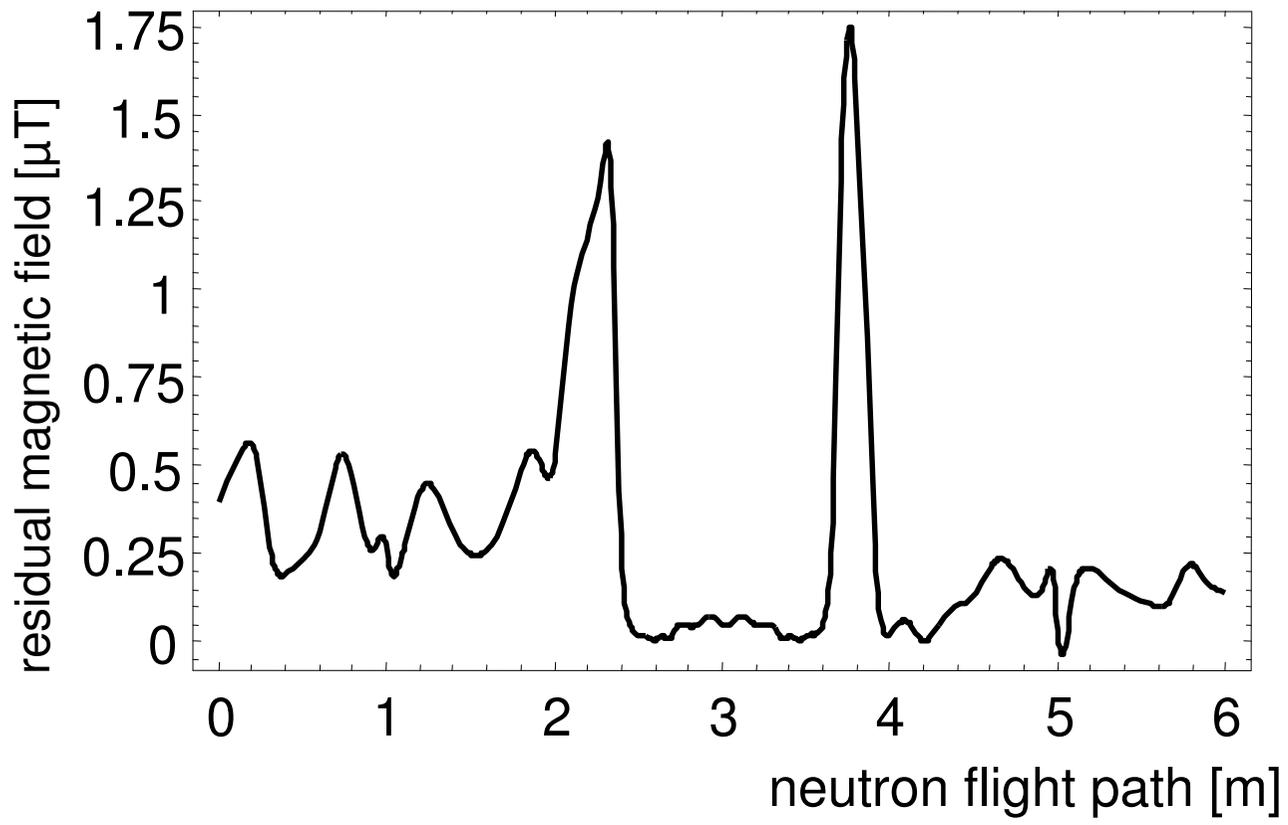


pictures from Sauli

Transparent Mode

- At gain 1, electric fields transport charges through the holes

The GEM inherently introduces high rates capability of 10 MHz/cm² !



$$\Lambda = 0.927$$

U. Kinkel
Z.Phys.C **54**, 573-575(1992)

$$P_{nn'}(t) = \left(\frac{t}{\tau_{osc}}\right)^2 \left[1 - \frac{4}{l^2} \int_0^l \int_0^{x''} \sin^2 \left(\frac{\gamma}{2v} (B_{int}(x') - B_{int}(x'')) \right) dx' dx'' \right]$$

length flight path

velocity of neutrons

Λ

B-field integral
along neutron flight path

gyromagnetic ratio

$$R = \frac{\text{count rate without magnetic field}}{\text{count rate with magnetic field}} = 1 - \left(\frac{t}{\tau_{osc}} \right)^2$$

measuring cycle:

- 0.5s without magnetic field
- switch magnetic field on, wait 0.1 s
- 0.5s with magnetic field
- switch magnetic field off, wait 0.1 s

length flight path: 6m , $\lambda = 11\text{\AA}$ $\Rightarrow v = 360\text{m/s} \Rightarrow t = 17\text{ms}$

2 day measurement, about 10^5 individual ratios R

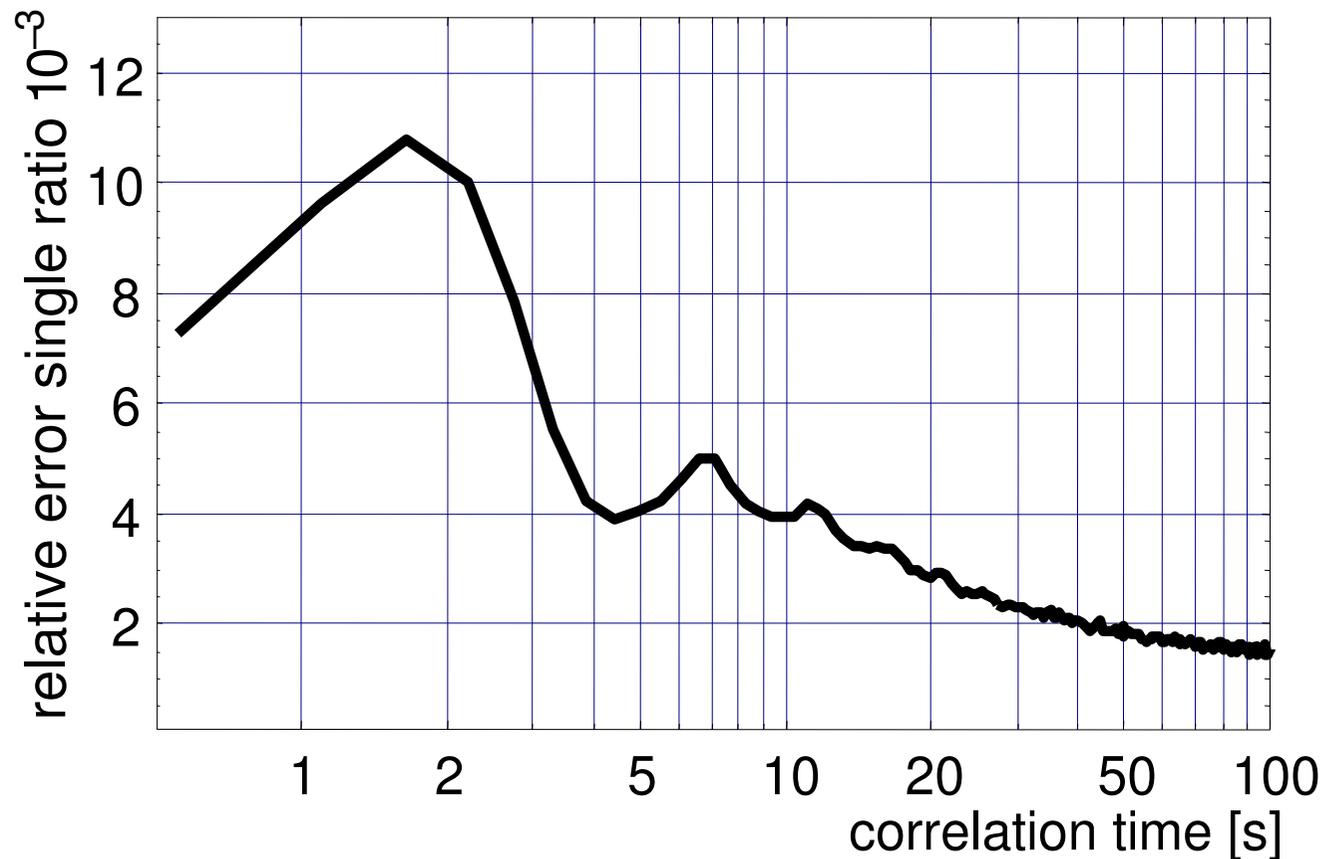
$$\frac{\overline{N_{B=0}}}{N_{B \neq 0}} = 1.000020 \underbrace{(27)}_{1\sigma} \Rightarrow \tau_{osc} \geq \cancel{2.7\text{s}} \quad (90\% \text{ confidence level})$$

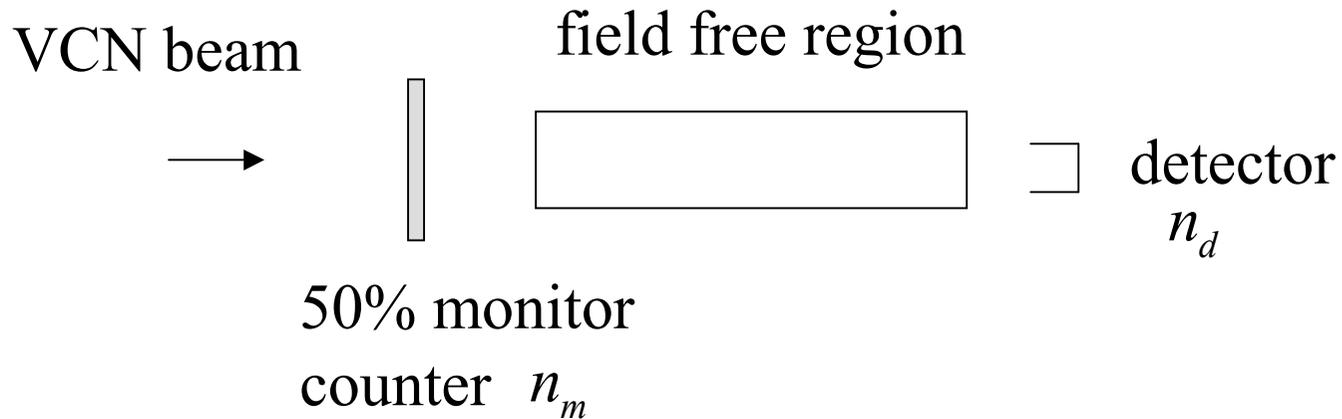
scattering (standard deviation) of the individual ratios: 0.0082

error of the individual ratios calculated from number of count: 0.0039

=> sensitivity is limited by intensity fluctuations of the beam

figure of merit $\propto \sqrt[4]{Nt}$





$$R^{\sim} = \frac{\frac{n_d}{n_m} \text{ (without magnetic field)}}{\frac{n_d}{n_m} \text{ (with magnetic field)}} = 1 - \left(\frac{t}{\tau_{osc}} \right)^2$$

noise of R^{\sim} will be much less than noise of R

Experiment FRM II

Barbara Böhm ¹

Wolfgang Häusler ²

Dominik Streibel ²

¹ Physikalisches Institut Heidelberg

² FRM II (Forschungsreaktor München II)

n

CASCADE detector

Martin Klein ¹

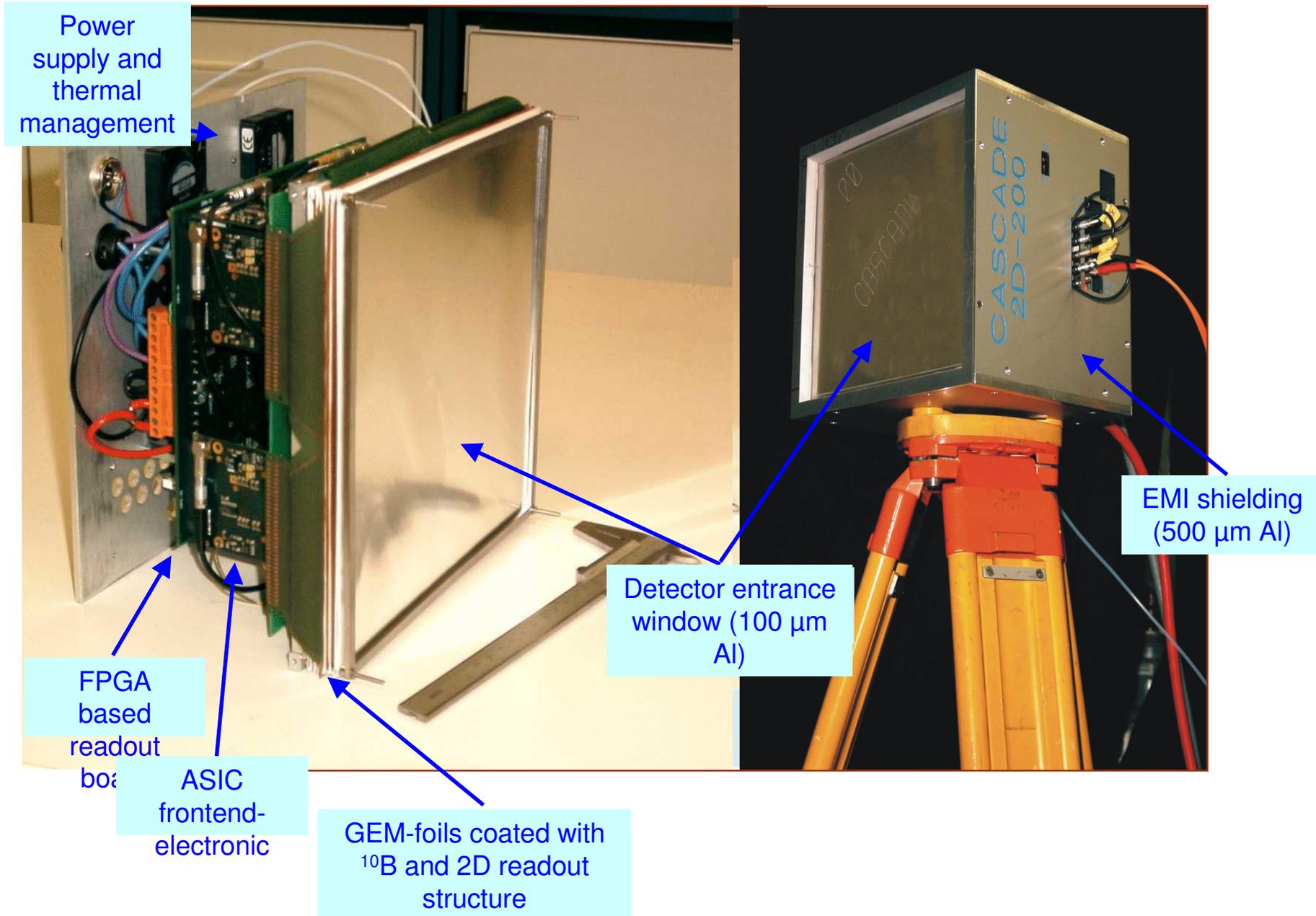
Gerd Mozel ¹

Jörg Betz ¹

Stefan Backfisch ¹

Thank you
for your attention

The Assembled 2D-Detector



Neutron-Pictures with the 2D-200 CASCADE Detector System

